The issue with turbulence modelling on wind turbine airfoils

Turbulence is a complex flow process dominated by seemingly chaotic eddy motions of multiple scales. Large eddies decompose into smaller eddies of nearly random appearance, but small eddies reorganize into larger coherent structures [1]. For high Reynolds numbers, turbulent processes are too complex to be fully resolved (DNS) in Computational Fluid Dynamics (CFD) simulations. Engineers use approximate equations (VRANS/LES) to handle turbulent phenomena with closure models [2, 3].

Errors in Load Prediction

from semi-empirical turbulence models with incomplete physics calibrated with insufficient data

(2, 3)

Gazing at clouds to understand turbulence on wind turbine airfoils

Adopt data rich approach to tune flow turbulence models

We propose to rethink the procedure for calibrating turbulence models used in popular Computational Fluid Dynamics (CFD) codes. Like Duraisamy at Michigan University [4, 5], we recognize that current turbulence models were calibrated with a single handful of reference cases, and therefore attempt to create a large unified calibration dataset. The large calibration dataset will be used to learn optimal conditional calibration rules for popular turbulence models. Our first experiment consisted in reproducing the way aerodynamicists work [2] with a genetic optimizer. For instance, RANS models like Spalart-Allmaras (SA) and LES subgrid scale (SGS) closure models were tuned to match a VI code (RFOIL) with genetic optimization algorithms.

Learn turbulence model calibration curves

There are many ways to learn from data. Our first experiment consisted in reproducing the way aerodynamicists work (2) with a genetic optimizer. The data pool was too narrow and asymptotic tendencies were unreliable. Our 2nd experiment, a simple version of (4), had a virtually unlimited data pool and used neural networks. Results were better, but computationally expensive. Data assimilation approaches used in EO [7] could yield better results.

Predict turbulent flows

Once established, the methodology will be applicable to any type of turbulent closure relation, thereby highlighting the common features of seemingly diverse schemes. Even when good calibration is achieved, turbulence models will still rely on many coarse assumptions: most popular RANS and LES closures rely on the Boussinesq hypothesis and rule some (if not all) anisotropy out.

Infer new closure terms

Model calibration curves can hint towards the most problematic simplifications behind current turbulence models [5], and neural networks can even learn improved closure terms [4]. But learning algorithms do not aim to replace researchers: like genetic airfoil optimizers enhance the work of aerodynamicists, neural networks can empower turbulence modellers.

Gather early experiments show that size of calibration dataset is critical for successful data driven turbulence modelling, motivating bridges to multidisciplinary fields.

Earth Observation (EO)

Data assimilation (3DVAR)

Turbulent Flow Database

Analytical Solutions

Cannondial flows

Semi-analytical solutions

Wind Tunnels

Industrial wind cases

Turbulent data base

Canonical flows

Instrumentation

5

Pressure Tap, Wake Rake, Load Balance, Particle image velocimetry (PIV)...

Ultrasonic Anemometry, Wind LIDAR, SCADA and Turbine Controller Data

N.A., Direct Numerical Simulation (to provide asymptotic behaviour)...

ADAM Aeolus Instrument, Lagragenan Tracers on OpenFlow Measurements

Instrumentation

4

Hot wire, PIV, Pressure Tap and Stanton Tube

LEARN TURBULENCE MODEL CALIBRATION CURVES

GATHER MEASUREMENTS OF VERY HIGH REYNOLDS FLOWS

PREDICT TURBULENT FLOWS

INFER NEW CLOSURE TERMS

Solution

1

A first course in Turbulence, Reutelingsperger

Deterministic Chaos, Kumar N, U. Press


Image 753x330 to 1108x461

Summer schools: JMBC Turb., Water Pipe Experiments

High Altitude Winds, Propulsion Loads by Durasaimy at Michigan University [4, 5], Turbgate (http://turbgate.engin.umich.edu/)?

Or should we develop a European alternative with broader perspectives on wind energy future?

Viscous-Inviscid

Flow

Navier Stokes

Large Eddy Filtered Navier Stokes

RANS

LES

Closure

Aerodynamics

Load Prediction

Navier Stokes

Vicous-Invviscid

Asymptotic

Turbulence Models

AEO Flow

Hold unique information on high Reynolds turbulent phenomena, essential to identify asymptotic tendencies.

SOLUTION

ADOPT DATA RICH APPROACH TO TUNE FLOW TURBULENCE MODELS

SOLUTION

"Big winds have little whirls that feed on their velocity, and little winds have been whirls and so on to viscosity."

"Perhaps the single, most critical area in CFD simulation capability that will remain a pacing item by 2030 (...) is the ability to adequately predict viscous turbulent flows."

Weather Prediction by Numerical Process Richardson LF, CUP

Turbulence remains the last unsolved problem of classical mechanics."

"Every flow is an observation of the phenomena of turbulence."

Tune the G-Beta constants of a viscous-inviscid (VI) solver (RFOIL) with genetic algorithms (NGA2).

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